Training Effectiveness

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An Evaluation of Training Effectiveness

of an Intelligent Tutoring System

Technical Report

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Abstract

The study evaluated the training effectiveness of an intelligent tutoring system (ITS) for the Remote Manipulator System (RMS). The study examined how well individuals learn the training content and skills from the RMS ITS and to what extent the content and skills learned using the ITS transfer to RMS task performance in the SES, a high fidelity simulator. Three astronauts completed 8 2-hour ITS sessions addressing movement in three coordinate systems, grapple, ungrapple, berth, and unberth procedures, and singularities and reach limits. Their performance was also observed in a SES training session. Performance data was collected using multiple measures: ITS task performance, transfer performance on the SES, a conceptual knowledge test, an opinion survey completed by astronauts, and comments and observations from astronauts and trainers. Results indicated the RMS ITS to be moderately effective and provided evidence of the efficacy of ITS's, in general. Comments and suggestions are provided relating to how the ITS could be improved and to enable decision makers to judge the effectiveness of the RMS ITS.

An Evaluation of Training Effectiveness

of an Intelligent Tutoring System

Education and training in industry is time-consuming and expensive. As tools and equipment become more sophisticated, training costs (both time and money) will increase also. Indeed, many of the tasks performed by NASA personnel, e.g., mission specialists or mission controllers, require extensive training and elaborate simulation equipment. Tools are needed to reduce the high training costs and time requirements on complex tasks. They are also needed to facilitate training in situations requiring sophisticated simulation equipment and where too few personnel are available to conduct the training.

Intelligent Tutoring Systems (ITS's) offer a means for addressing these training needs. ITS's have already been developed to teach a variey of topics and task activities in educational settings and to a lesser extent in industry settings (Wenger, 1987). Moreover, ITS's have been recently developed at NASA to provide training on specific tasks (e.g., Payload-assist module Deploys, RMS use) and a general architecture has been proposed to reduce the costs and time required to build ITS's for other tasks (Loftin, Wang, Baffes, & Hua, 1988).

As a result of building new ITS's, much attention has been given to the design issues of ITS's (based on Loftin's general architecture [Loftin et al., 1988]). However, little attention has been given to evaluation of ITS's. Evaluation is thought to be time consuming and costly (Frye, Littman, & Soloway, 1987). Moreover, there are not clear guidelines for how to assess a system's effectiveness (Burns & Capps, 1988). Traditional training evaluation tools and procedures (e.g., Goldstein, 1986) offer a starting point but may not be sufficient to evaluate ITS's (Goldstein, 1989).

Traditionally, evaluation has been discussed in terms of two categories: formative and summative (Scriven, 1967). Formative evaluation investigates whether the program is operating as planned or if improvements are needed before a program is implemented. Summative evaluation examines the effectiveness of the final product. Given the newness and exploratory nature of many ITS's, the focus of evaluation of ITS's should be more on formative evaluation (Littman & Soloway, 1988). Indeed, of the few evaluation efforts reported to date, most have been formative. However, most evaluations have also been relatively informal (Littman & Soloway, 1988). Further, some evaluation efforts have been primarily descriptive or qualitative in nature (see Wenger, 1987, p. 59, p. 133 for examples) or have used weak experimental designs such as pre-test and post-test with no control groups (see Wenger, 1987, p. 96). A few more rigorous evaluations have been completed, but primarily in the lab or in educational settings (e.g., Anderson, Boyle, & Reiser, 1985). Few evaluation efforts have been completed in industrial settings, although more attention is beginning to be focused on this (Govindaraj, 1988).

Evaluation efforts to date are also likely to be small in number and more informal because guidelines are not yet well developed for evaluating ITS's. One set of guidelines offered for performing formative evaluations focuses on external and internal evaluation (Littman and Soloway, 1988). Internal

evaluation focuses on the system's architecture (which is beyond the scope of the current project). External evaluation focuses on how the system affects students' problem solving processes. The rationale underlying external evaluation is that using a more traditional evaluation approach of assessing correct versus incorrect performance is not of sufficient detail. To more properly evaluate the system, one also needs to examine the reasons underlying students' errors. Information on the types of errors students make can then be used to improve the remediation provided to students. The interest in using a more fine-grained analysis of students' performance reflects the purpose of formative evaluation: to improve an ITS in development. The coarser, but still important, measures relating to correct versus incorrect performance reflect a focus on summative evaluation.

Purpose

The purpose of the current research project was to evaluate the training effectiveness of an ITS developed for training RMS tasks. It was not possible to examine the ITS in relation to other training interventions. Thus, the relative effectiveness of the RMS ITS compared to other forms of training was beyond the scope of this study and remains a question for furture research. Rather, this study focused on examining comprehensive information related to the RMS ITS.

The project extended previous evaluation research in two ways. First, the evaluation attempted to apply a set of guidelines proposed (Littman and Soloway, 1988) for conducting an external, formative evaluation. Previous work by the author examining other ITS's at NASA also had a more formative focus although it relied more on coarser measures, e.g., counts of subtasks completed or number of errors (Johnson, 1989, 1990). In addition, previous work by the author reported some descriptive or qualitative information, e.g., ITS user impressions. Thus, this earlier work provided a foundation for expanding evaluation techniques to use more fine-grained measures.

The current study attempted to collect more fine-grained data using a two-part approach. More specifically, we used a variety of measures of learning and performance, including assessing ITS task performance, transfer of training performance on the SES, a conceptual knowledge test, a survey of opinions collected from the astronauts, as well as comments and observations from the astronauts and task experts, i.e., the trainers. Moreover, multiple, fine-grained dimensions of performance were assessed on the ITS and SES, including number of trials failed, time required per trial, accuracy, efficiency, camera use, etc.

This two-part approach offered the opportunity to examine detailed information on knowledge and performance and provided an opportunity to draw stronger conclusions regarding the results to the extent that data collected using different measures converged. This also enabled the researcher to state some conclusions although data was only available for a few subjects. Given the demands placed on astronauts, access to large numbers of subjects was not possible. Thus, more comprehensive data was needed to enable decisions regarding ITS effectiveness, especially data collected using diverse measures.

This approach was consistent with Kirkpatrick (1977) who described four levels of evaluation: reactions, learning, performance, and effectiveness. Reaction criteria refer to individuals' thoughts and feelings about the program. This data was collected in the current study through information comments and an opinion survey. Learning criteria are more rigorous and address skill mastery or assessment of concept understanding. This could be called the validity of training. In the current study we collected objective performance data on the RMS ITS and administered a conceptual knowledge test. Kirkpatrick's performance criteria refer to the extent to which skills and knowledge learned during training transfer to job performance. This was referred to as transfer of training in the current study and was assessed by examining performance on the SES. Finally, effectiveness criteria refer to measures of training results in the organization which was not directly examined in the current study.

Second, the ITS evaluation combined aspects of both formative and summative evaluation. Although a formative evaluation approach was more appropriate given the newness of the ITS, aspects of a summative evaluation, e.g., performance accuracy or time requirements, could aid decision makers in making initial judgments of the effectiveness of the RMS ITS as a training tool and of the efficacy of ITS's in general.

Method

Subjects

Three male astronauts who were scheduled to begin Remote Manipulator System (RMS) 2000 level training participated in a modified training program incorporating an RMS ITS. The RMS is a robotic arm used to deploy and/or retrieve shuttle payloads (e.g., satellites). The astronauts were informed that the training they would be receiving was a modified version of the traditional level 2000 training and were given a description of the modified training flow. Their participation was voluntary, and informed consent was obtained. The astronauts were also debriefed at the end of the project.

Training Modifications and Research Project Procedure

The ITS-modified RMS training affected the content of three RMS 2000 level training modules: PDRS OPS 2124, PDRS NOM OPS 2124, and PDRS NOM OPS 2115. These three modules usually require a total of 8.5 hours of training time. However, they required a total of 4.5 hours in the modified training curriculum because training content which replicated ITS training content was removed. In addition, performance information was collected during PDRS NOM OPS 2215 (3.5 hours). Subjects completed RMS 2000 level training modules through MDF FAM 2324 with no modifications. They then completed eight, 2-hour RMS ITS training sessions in parallel with the three modified modules (PDRS OPS 2124, PDRS NOM OPS 2124, and PDRS NOM OPS 2115). The RMS 2000 level training sequence was increased by 12 hours to incorporate the ITS. As part of an early RMS ITS training session, subjects received an one-hour briefing RMS coordinate systems from a Shuttle trainer. Subjects 1 and 3 received an 1-hour briefing during ITS Session 4; Subject 2 received a 2-hour briefing on both coordinate systems and the PDRS Overview information during ITS Session 1. Also, subjects had access to the "Payload Deployment and Retrieval System Overview Workbook" (PDRS OV 2102) used

in Shuttle RMS training. Performance data was collected during the PDRS NOM OPS 2215 training module on the SES; this module was unmodified except for the observation and recording of subject performance on a subset of the tasks performed. Subjects then returned to the original training flow, receiving the same subsequent RMS training as all other astronauts.

ITS Tasks: Description and Performance Measures

The RMS 2000 level training was supplemented with lessons from the P2T2 RMS ITS developed by Global Information Systems Technology (NASA P2T2 Intelligent Trainer Final Report, 1991). The ITS overlaid training content on the P2T2, an existing kinematic simulator of the shuttle's robotic arm. The ITS-modified training included ITS lessons on the Orbiter Unloaded, Orbiter Loaded, and End Effector coordinate systems as well as ITS lessons on Grappling, Ungrappling, Berthing, Unberthing, Recognizing Singularities, Visualizing Singularities, Recognizing Reach Limits, and Visualizing Reach Limits. These lessons were a subset of the part tasks (i.e., subtasks of deploys or retrievals) available on the ITS. The ITS also provided part tasks on the Payload coordinate system and Loaded and Unloaded Arm Phasing which were not used in the current study. The Payload part task was not used due to a 180 degree reversal in one of the axes included in the part task. This reversal was discovered by a trainer after the project began. The task could have been changed to reverse the axis but it was decided that experience with the other three coordinate systems would be sufficient for the evaluation of the ITS, especially given the time constraints of the astronauts. The Loaded and Unloaded Arm Phasing part tasks were not used because they used concepts addressed in earlier part tasks. Finally, two whole tasks--Retrieval and Deploy tasks--were available on the ITS but were not used for this project due to time constraints.

To perform ITS lessons, subjects used translational and rotational hand controls, a keyboard, and a control box to manipulate task components viewed on a computer monitor. The left hand control, the translator, enabled movement of the RMS on the X, Y, and Z axes with the orientation of the axes dependent on the coordinate system being used. The right hand control enabled rotation of the RMS on the X, Y, and Z axes, with the orientation again dependent on the coordinate system being used. The keyboard was used to enter information related to the payload. The control box enabled subjects to change settings on the control panel viewed on the computer monitor.

The computer monitor displayed four windows. The lower left window displayed the control panel which was accessed through the control box. The control panel enabled the control of various RMS operations, e.g., the selection of the appropriate Mode--Unloaded, Loaded, etc. The upper left and upper right windows offered views of the RMS and shuttle bay, with the view dependent on camera selection and orientation. The control box enabled one to manipulate camera views in these two windows. Finally, the lower right window provided task status information and ITS task controls which were accessed using a mouse (e.g., exit the ITS, go on to the next task). For more complete information on displays and ITS usage, see the P2T2 Intelligent Trainer Final Report (Global Information Systems Technology, 1991).

Coordinate System Tasks. Subjects completed ITS part tasks relating to the Orbiter Unloaded, Loaded, and End Effector coordinate systems. Part tasks are subtasks of the deploy and retrieval tasks. The part tasks relating to coordinate systems aided subjects in visualizing and moving the RMS. For each coordinate system, subjects first performed a set of translation tasks. The translation tasks had four levels of complexity (LOC's): movement in one, two, then three dimensions, and finally movement of greater distance in three dimensions and without a ghost arm (indicating the target position). Subjects next performed a set of rotation tasks, completing the same four levels of complexity. Then, subjects completed a set of integrated tasks requiring both translation and rotation, again at four levels of complexity. Subjects completed the translation, rotation, and integrated hand control tasks for the Unloaded, Loaded, and finally the End Effector coordinate systems.

Within each level of complexity, subjects performed 2 to 5 trials. If subjects passed the first two trials, they were advanced to the next level of complexity. Otherwise, subjects were required to pass 5 successive trials to advance to the next level of complexity. Generally, if the subject failed a trial, s/he was required to reattempt the 5 successive trials required to pass to the next level of complexity. However, if the subject passed 3 or 4 trials, then failed a trial but passed the next, the subject was given another chance before being required to reattempt the 5 successive trials required to advance. This was true of both the coordinate systems and the procedural part tasks.

Performance on the coordinate system part tasks was assessed in terms of accuracy and efficiency. Accuracy accounted for 75% of the overall score and efficiency for 25%. Subjects were required to attain at least 75 total points (out of 100) to pass the trial. The default criteria levels provided by the RMS ITS were used (Global Information Systems Technology, 1991). That is, accuracy referred to the distance from the target coordinates upon task completion. The translation allowance was 5 inches. The rotation allowance was 5 degrees for roll and 8 degrees for pitch and yaw. Efficiency referred to the path and time, with path accounting for 80% of the efficiency score. The minimum passing score (a score of 75) for path was 1.5 times the minimum distance or rotation, i.e., no more than 50% farther than the minimum distance or rotation possible. For the time criteria, the minimum passing score (75) was obtained if one used the time allowed. A subject earned the maximum score on time (100) if s/he performed the task in half the allowed time.

Procedural Tasks. Subjects next completed a set of part tasks involving procedures. The procedural part tasks required the performance of sequences of actions based on the PDRS Operations Checklist: P2T2 Flight Supplement Generic Procedures (see Appendix A). The Generic Procedures were developed by the Space Shuttle and Space Station Programs. Subjects were provided with a copy of the Generic Procedures and referred to this document as they performed the Grapple, Ungrapple, Berth, Unberth, Recognizing Singularities, Visualizing Singularities, Recognizing Reach Limits, and Visualizing Reach Limits part tasks.

The procedural tasks are categorized into two groups for ease of description below. The groups were determined by the similarity of the scoring procedures. The **Grapple, Ungrapple, Berth, and Unberth** tasks will be described first. For the Grapple task, the RMS started in pre-grapple position and subjects completed

the grapple procedure (see Generic Procedures in Appendix A). There were three levels of complexity. In LOC 1 the camera views were preset for subjects. In LOC 2, subjects were required to adjust camera views. In LOC 3, subjects were required both to adjust camera views and grapple payloads with fixtures in different locations (e.g., top, side). The Ungrapple task involved the ungrapple or release procedures and movement to the pre-grapple position. In LOC 1, subjects completed the Release procedure using preset camera views. In LOC 2, subjects completed the Grapple procedure and were required to adjust the camera views. In LOC 3, subjects alternately completed the Ungrapple and Release procedures, again adjusting camera views. The Berth task involved berthing the payload starting from the "low hover" position, i.e., from a position directly over the V-guides. LOC 1 offered subjects preset camera views and visual cues on the monitor. LOC 2 and 3 required the adjustment of camera views, and LOC 3 also varied the position of the grapple fixture. The Unberth task involved unberthing the payload and moving it to "low hover" position. The LOC's were the same as for the Berth task.

Within each LOC, subjects were required to pass 3 successive trials to advance to the next level. Subjects' performance was again based on accuracy and efficiency; however, subjects were also evaluated on safety, correctness of procedure, and camera use. Accuracy referred to acceptable distances from the RMS to the target position and attitude for the task. The translation allowance was 8 inches for the grapple and berth tasks; the rotation allowance was 2 degrees for the berth task. Other allowances were the same as for the coordinate system tasks. Efficiency referred to path and time. Fly-to's, i.e., movement of the RMS, during the task were required to be at most 1.76 times the minimum translation and rotation to pass the trial. Simultaneous hand controller use was required to occur at least 50% of the time possible to pass. The time criteria were the same as for the coordinate system tasks. Safety referred to preventing contact of the RMS with any other structure. Points were deducted for each collision (25 points), movement in coarse rate when one should be in vernier rate (4 points), entering direct mode (10 points), and movement into a reach limit or singularity (10 points). Procedure referred to whether the correct sequence of actions was completed. Twenty points was deducted for each procedure error. Camera Use referred the percentage of time the cameras were used correctly.

The second group of procedural part tasks included Recognizing Singularities, Visualizing Singularities, Recognizing Reach Limits, and Visualizing Reach Limits. For the Recognizing Singularities task, subjects identified shoulder yaw, wrist yaw, and planar pitch singularities in LOC's 1, 2, and 3, respectively, and singularities of any type in LOC 4. For the Visualizing Singularities tasks, subjects identified the type of singularity likely to occur from given RMS configurations, identified the type of input required to drive the RMS into singularity, drove the RMS into the singularity, and resolve the singularity, adjusting camera views as necessary. In LOC 1 singularities were obvious and preset camera views were used. LOC 2 required camera view adjustment. LOC 3 used less obvious singularities and required camera view adjustment. For the Recognizing Reach Limits task, subjects identified 6 reach limits with the 6 LOC's reflecting the shoulder yaw, shoulder pitch, elbow pitch, wrist pitch, wrist yaw, wrist roll reach limits, respectively. For the Visualizing Reach Limits tasks, subjects performed the same four subtasks as for the Visualizing Singularities task.

Within each LOC, subjects were required to pass 3 consecutive trials to advance out of the Recognizing tasks and 5 consecutive trials to advance out of the Visualizing tasks. Subjects' performance on the Recognizing tasks was based on Accuracy, i.e., correct/incorrect identifications. Subjects' performance on the Visualizing tasks was also evaluated on Accuracy (correct/incorrect) for the identification subtasks. Points were deducted for each incorrect identification after the first attempt for singularities (25 points) and reach limits (20 points); 5 points were deducted for each initial incorrect hand controller choice for either task; 15 points were deducted for each additional incorrect hand controller choice. The Accuracy score was also reduced for hitting a reach limit (in singularity task) (50% reduction), hitting a software stop (75%), and hitting a hardware stop (100%). In addition, 35 points were lost for failure to drive into a reach limit, 20 points for failure to drive RMS into a singularity, 20 points for failure to resolve a singularity, and 20 points for failure to drive into a target RMS configuration. Camera use and Efficiency were also assessed as described above for other procedural tasks.

Survey of Content Knowledge

Subjects completed a written survey of content knowledge, addressing their understanding of coordinate systems, sequences of RMS task activities, and singularities and reach limits upon completion of all ITS lessons (see Appendix B). The survey was administered immediately prior to the SES lesson in which performance was observed. Thus, the test was administered between three and four weeks following the last ITS lesson.

Transfer Performance Measures

Following the ITS lessons, subjects completed the PDRS NOM OPS 2215 RMS 2000 level training module. This module involved performance on the SES of a variety of RMS tasks. Subjects' performance was observed on 5 tasks during the SES training session: fly-to positions/attitudes, grapple, ungrapple, berth, and unberth procedures. Four raters (one experimenter and three trainers) assessed subjects' performance on dimensions of these tasks (see Appendix C).

Qualitative Data

Qualitative data was also collected both from astronauts and trainers. Astronauts completed an opinion survey relating to the ITS (see Appendix D), addressing their reactions to, and suggestions for modifications of the ITS. Further, their informal comments were solicited and recorded during the ITS lessons and during the PDRS NOM OPS 2215 training module.

In addition, comments were solicited and recorded from two trainers who possessed Space Shuttle and/or Space Station training experience. Comments were solicited informally throughout the project and in a formal meeting after the completion of other data collection.

Results

Coordinate System Tasks

Unloaded Part Tasks. Mean performance data across the three subjects for the Unloaded part tasks are shown in Table 1. Two types of information are presented. Within each LOC, each subject performed at least two task trials in order to advance to the next LOC. Thus, for each LOC, subjects' performance averaged across the task trials required to advance to the next LOC is presented. In addition, performance data averaged across subjects' single best task trials within each LOC are presented.

As shown, subjects required approximately 8 trials to pass the THC tasks, 2 trials to pass the RHC LOC 1, 3, and 4 tasks, and between 2 and 5 trials to pass the Integrated LOC 1, 3, and 4 tasks. The 28 trial mean in THC LOC 3 was due to one subject who required 50 trials to pass this task. Also of interest was the apparent difficulty of learning tasks requiring movement in 2 dimensions (LOC 2). For the RHC and Integrated tasks, subjects found learning 2-dimensional movement the most difficult. Movement in 1 dimension presented few problems. Further, once movement in 2-dimensions was mastered, movement in 3 dimensions (LOC 3) or across longer distances without a ghost arm (LOC 4) presented relatively difficulty.

As expected, the time required to perform the tasks increased with the level of complexity involved (LOC 1 through 4). Also, subjects focused more on accuracy than on efficiency. Subjects were told that accuracy was more important than efficiency, and accuracy was a more important component of the total score. The lower efficiency scores reflect the greater emphasis on accuracy.

Loaded Part Tasks. Mean performance data for the Loaded part tasks are shown in Table 2. Performance of the Loaded part tasks appeared to be easier for subjects, with subjects requiring approximately 2 trials to advance to the next LOC. This was expected given the similarity to the Unloaded part tasks. Only the Point of Resolution (POR; the origin of the coordinate system) differed for the two tasks, with the POR in the tip of the end effector for the Unloaded tasks and at a point in the payload (e.g., 6 inches from the tip of the end effector) for the Loaded tasks.

Subjects required somewhat more time on average to perform the RHC tasks in the Loaded mode (between 32.7 and 202.7 sec.) than in the Unloaded mode (between 23.7 and 103.2 sec.). Also, subjects again focused more on accuracy than on efficiency, receiving substantially higher accuracy scores.

End Effector Part Tasks. Mean performance data for the End Effector part tasks are shown in Table 3. All three subjects performed THC LOC 1 through 4 tasks for the End Effector mode. However, no subject passed LOC 4. Further, due to time constraints and subject preference, only one subject performed the RHC (only LOC 4) and Integrated (only LOC 1 through 3) part tasks.

Performance of the End Effector THC part tasks appeared to be more difficult for subjects than the Loaded THC part tasks, requiring between 4.7 and 9.3 trials to pass LOC 1 through 3. In LOC 4, one subject performed 5 trials and a second

subject performed 27 trials without passing the task (i.e., passing 5 successive trials). Only one subject performed any other End Effector tasks. This subject required 2 trials to pass RHC LOC 4 and Integrated LOC 1 and 2, but 13 trials to pass Integrated LOC 3.

However, the time required to perform task trials was similar to the Unloaded tasks, ranging from 22.7 to 146.4 sec. for the THC, RHC, and Integrated tasks. Also, similar to the Unloaded and Loaded part tasks, subjects focused more on accuracy than on efficiency and received lower efficiency scores.

Table 1. Mean Performance for Unloaded Part Tasks.

Variable	THC LOC 1	THC LOC 2	THC LOC 3	THC LOC 4	RHC LOC 1	RHC LOC 2	RHC LOC 3	RHC LOC 4
# of Trials Required to Pass	8.3	8.3	28.0	7.0	2.0	9.0	2.0	2.0
# of Trials Failed	2.3	3.7	8.7	2.7	0.0	2.7	0.0	0.0
Average Time per Trial (Sec.)	26.3	35.5	38.8	68.2	27.3	88.3	80.7	103.2
Best Trial Time (Sec.)	17.7	18.0	32.0	50.0	25.7	50.0	71.3	70.3
Average Total Score	89.9	82.6	80.4	80.7	94.8	86.3	92.9	91.1
Best Trial Total Score	95.7	92.9	90.3	94.0	98.2	95.5	94.7	94.6
Average Accuracy Score	94.5	87.0	82.9	87.2	98.5	96.4	98.3	98.2
Best Trial Accuracy Score	97.6	92.5	94.0	96.7	99.7	98.6	98.9	98.0
Average Efficiency Score	76.0	69.3	72.7	61.3	83.9	56.0	76.6	69.6
Best Trial Efficiency Score	90.1	94.1	79.3	85.9	93.7	86.2	82.1	84.2

Table 1 Continued. Mean Performance for Unloaded Part Tasks.

Variable	INTEG LOC 1	INTEG LOC 2	INTEG LOC 3	INTEG LOC 4
# of Trials Required to Pass	4.7	18.0	2.0[1]	3.7[1]
# of Trials Failed	1.3	11.7	0.0	0.7
Average Time per Trial (Sec.)	133.2	148.0	159.7	195.8
Best Trial Time (Sec.)	59.0	111.3	138.0	153.5
Average Total Score	86.1	79.6	84.8	85.0
Best Trial Total Score	94.5	88.1	87.2	92.5
Average Accuracy Score	94.6	91.1	96.2	94.0
Best Trial Accuracy Score	97.6	94.4	96.6	96.7
Average Efficiency Score	60.2	45.4	50.6	58.0
Best Trial Efficiency Score	85.3	69.1	59.2	79.8

[1] Data based on two subjects. Due to time constraints, one subject did not complete LOC 3 and 4.

Table 2. Mean Performance for Loaded Part Tasks.

Variable	THC LOC 1	THC LOC 2	THC LOC 3	THC LOC 4	RHC LOC 1	RHC LOC 2	RHC LOC 3	RHC LOC 4
# of Trials Required to Pass	2.0[1]	2.0[1]	2.0	2.0	2.7	2.3	2.7	3.7
# of Trials Failed	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3
Average Time per Trial (Sec.)	29.5	50.0	54.7	68.2	61.4	229.7	200.4	169.4
Best Trial Time (Sec.)	23.0	37.0	54.7	61.0	32.7	175.7	202.7	152.3
Average Total Score	97.8	93.3	92.0	94.0	96.5	85.3	84.5	88.8
Best Trial Total Score	99.3	98.1	92.6	95.4	99.5	89.9	94.3	94.7
Average Accuracy Score	97.6	96.5	94.9	95.6	98.8	98.3	89.8	93.8
Best Trial Accuracy Score	99.5	98.2	94.7	97.1	99.6	98.9	98.2	98.6
Average Efficiency Score	98.3	83.6	83.2	89.2	89.5	46.5	68.8	74.0
Best Trial Efficiency Score	98.6	97.9	87.0	90.1	99.2	62.3	82.5	83.2

[1] Data based on two subjects. Data for one subject was not recorded by the ITS.

Table 2 Continued. Mean Performance for Loaded Part Tasks.

Variable	INTEG LOC 1	INTEG LOC 2	INTEG LOC 3	INTEG LOC 4
# of Trials Required to Pass	2.0	2.0^2	2.0^3	2.0^3
# of Trials Failed	0.0	0.0	0.0	0.0
Average Time per Trial (Sec.)	130.2	199.8	175.0	155.5
Best Trial Time (Sec.)	127.3	191.0	159.5	153.5
Average Total Score	87.0	82.0	89.3	87.2
Best Trial Total Score	90.0	82.6	91.5	87.6
Average Accuracy Score	97.5	96.8	97.2	96.7
Best Trial Accuracy Score	98.2	96.9	97.9	96.3
Average Efficiency Score	55.5	37.9	65.7	58.8
Best Trial Efficiency Score	65.2	39.8	72.7	61.3

[2] Data reported for three subjects; however, one subject completed only one trial thus did not pass this LOC. His data was excluded from the # of Trials Required to Pass and # of Trials Failed measures.

[3] Data provided only for two subjects. One subject did not complete LOC 3 and 4.

Table 3. Mean Performance for End Effector Part Tasks.

Variable	THC LOC 1	THC LOC 2	THC LOC 3	THC LOC 4	RHC LOC 1	RHC LOC 2	RHC LOC 3	RHC LOC 4
# of Trials Required to Pass	7.0[1]	4.7	9.3	10.7[2]	--	--	--	2.0[1]
# of Trials Failed	1.0	1.7	2.7	6.0	--	--	--	0.0
Average Time per Trial (Sec.)	22.7	51.3	61.9	103.0	--	--	--	73.5
Best Trial Time (Sec.)	18.0	34.3	43.7	80.5	--	--	--	75.0
Average Total Score	94.3	80.8	82.5	59.6	--	--	--	90.2
Best Trial Total Score	99.3	93.1	92.2	90.4	--	--	--	90.5
Average Accuracy Score	97.6	85.56	89.5	68.5	--	--	--	96.3
Best Trial Accuracy Score	99.5	94.9	95.6	96.9	--	--	--	95.8
Average Efficiency Score	84.3	66.4	61.7	32.7	--	--	--	71.7
Best Trial Efficiency Score	98.8	88.1	82.3	70.9	--	--	--	74.4

[1] Only one subject completed this LOC.
[2] Only two subjects performed trials in this LOC; neither passed this LOC. Data on all performance measures is provided for these two subjects.

Table 3 Continued. Mean Performance for End Effector Part Tasks.

Variable	INTEG LOC 1	INTEG LOC 2	INTEG LOC 3	INTEG LOC 4
# of Trials Required to Pass	2.0^1	2.0^1	13.0^1	--
# of Trials Failed	0.0	0.0	1.7	--
Average Time per Trial (Sec.)	59.5	109.0	146.4	--
Best Trial Time (Sec.)	50.0	93.0	114.0	--
Average Total Score	86.0	84.6	75.7	--
Best Trial Total Score	90.1	91.0	86.8	--
Average Accuracy Score	92.4	95.2	89.4	--
Best Trial Accuracy Score	93.1	95.5	94.3	--
Average Efficiency Score	66.2	52.7	34.5	--
Best Trial Efficiency Score	81.2	77.4	64.0	--

[1] Only one subject completed this LOC.

Informal Comments and Observations. Subjects provided variety of comments and observations relating to the coordinate system part tasks. In the Unloaded part tasks, two subjects relied on the ghost arm as the target and were unaware of the digitals displayed on the screen until THC LOC 2 in one case and THC LOC 4 in the other case when the ghost arm no longer appeared. One subject suggested we emphasize the digitals displayed to reduce reliance on the ghost arm. (However, RMS trainers might not agree with this suggestion, instead recommending subjects focus on visualizing the target position and attitude rather than relying on the digitals.) At the end of the End Effector part tasks, one subject questioned why the ghost arm was removed in LOC 4 for the coordinate systems part tasks. He suggested that this focused subjects more on the digitals. However, he also reported learning more from the digitals and ignoring the ghost arm.

Two subjects also had difficulty with the Unloaded RHC part tasks, reporting that the RMS often moved in a different direction than expected based on the RHC inputs. One subject reported relying more on the digitals due to the difficulty in visualizing the target attitude. These subjects had not yet received the

briefing on coordinate systems from the Shuttle trainer. One subject specifically requested instruction from a Shuttle trainer on the RHC task. Due to scheduling constraints, he did not receive the briefing on coordinate systems, including RHC tasks, until completion of the Unloaded and Loaded part tasks. This subject thought he had learned the wrong technique for RHC tasks, and he thought he needed to repeat the previous RHC lessons because he had been working with the digitals rather than trying to visualize the target orientation of the RMS. This subject also reported that early coaching with a Shuttle trainer could help ensure subjects learn the correct approach and further suggested that it might be appropriate to learn the basics on the MDF and other simulators and then practice on the ITS.

One subject received the briefing on coordinate systems prior to beginning the Unloaded part task. This subject appeared to experience much less difficulty in performing RHC tasks based on his comments versus the other subjects' comments. However, this subject also found the RHC tasks more difficult than the THC tasks. Further, he reported that he felt the ITS focused the individual on digitals alone. He did not know how realistic this was in relation to RMS tasks but felt that the information was valuable at his stage of learning. This subject reported that seeing the changes in the digitals and the corresponding motion on the screen was useful.

The experimenter's informal observation was that all three subjects appeared to find the RHC tasks more difficult than the THC tasks. However, the subject receiving the briefing on coordinate systems in ITS Lesson 1 appeared to experience less difficulty with the RHC tasks than the other subjects. The other subjects also appeared to find the briefing from the trainer very helpful. The experimenter's informal observation was that the Workbook alone was not sufficient to prepare subjects for the RHC tasks on the ITS; further, the ITS did not provide sufficient information to enable subjects to understand RHC tasks.

Two subjects commented on the God's eye view displayed in the upper right window and questioned its usefulness. One subject commented that it would be helpful to know where the cameras were located from which one viewed the RMS. He also noted that the "God's eye view" was not an actual camera view available on the shuttle. Another subject felt the God's eye view was not appropriate because it did not provide a true reference point. These subjects suggested having the ITS provide two real views in the upper windows of the display or having the ITS provide one view and the subject select the camera view in the other window. The two lower windows displayed the control panel and performance or ITS use information. (Note: The God's eye view was not provided in LOC 3 and LOC 4 tasks but could be accessed using the God's Eye View Hint button.) One subject also noticed that if he replaced the God's eye view with another camera view, he could not reobtain the God's eye view.

Two subjects commented on the ability to display the POR in the Loaded part tasks. Both subjects had to be told that they could highlight the POR by placing the cursor in a window viewing the RMS or shown how to display the wire frame version of the RMS. The ITS did not provide this information. However, only one subject found highlighting the POR helpful, wanting to see the location of the POR on the screen. The other subject reported that highlighting the POR during RHC tasks did not provide particularly useful information. (Neither subject had

yet received the briefing on coordinate systems.)

One subject commented that he would like to be able to go back and repeat any previous task to obtain additional practice. He did not like the fact that the ITS made it mandatory to continue to the next LOC upon passing a task. He purposely failed trials to obtain additional practice.

One subject also reported that the Advanced Organizers, the text information and instructions presented prior to each part task, did not provide sufficient information to understand or perform the task. The information was sufficient to perform the mechanics of the tasks, but subjects appeared to want more information to increase their conceptual understanding of the tasks.

One subject expressed concern about not getting adequate time on the higher fidelity simulators (i.e., MDF, SMS, SES) due to the time spent on the ITS. (Note: The ITS affected 3 out of 25 RMS 2000 level training modules and replaced 4 hours out of 49.5 hours usually spent on the MDF, SMS or SES.)

One subject experienced a computer problem in that the RMS was moving by itself when the ITS program was running. The problem was resolved by exiting and reentering the ITS program. Also, one could reset the null position in the hand controller by "jiggling" the hand controller.

One subject reported feeling very pressured in terms of time and accuracy. He felt like the machine was going to "beep" at him at any time. This subject also expressed a desire to be able to pause the trial to figure something out or think about something.

Two subjects preferred to not complete the End Effector tasks. One subject felt he had not mastered the tasks but was still trying to "beat the system", and he did not think practice with another coordinate system would change this. The second subject felt that the End Effector tasks were unrealistic: they did not reflect the use of this mode in actual RMS tasks, and the ITS End Effector tasks should be revised. Both subjects were advanced to the procedural part tasks.

Also, all three subjects at some point reported they were focused more on "beating the system" than on learning the tasks. Subjects felt that the ITS instructions or tasks cued this attitude. However, one subject also reported that the coordinate system lessons were useful in learning how to maneuver the hand controllers and in learning the uniqueness of each coordinate system, although he felt the LOC 4 tasks were not needed.

Finally, the experimenter had to explain to each subject how to move the parameter dial to get digitals for either position or attitude. The ITS did not provide this information. Further, during some part tasks, the ITS processed commands slowly.

Procedural Tasks: Grapple, Ungrapple, Berth, and Unberth

Grapple Tasks. Mean performance data for the Grapple procedural part tasks are shown in Table 4. Performance of the Grapple part tasks appeared to be relatively easy for subjects, with subjects requiring between 2 and 3 trials on

average to advance to the next LOC and failing between 0 and .33 trials on average. Subjects generally required between 100 and 180 seconds to perform the task, with their best trials requiring between 90 and 160 seconds. Further, they performed the task both accurately and efficiently with average scores above 88%. Safety and camera scores were also high (scores above 95% and 85%, respectively). However, procedure scores were somewhat lower, ranging between 63% and 71% on average and between 67% and 87% on their best trials. This might be due to some confusion regarding which step in the P2T2 Generic Procedure was the starting point in the ITS task as well as how close a view of the grapple fixture was required (see informal comments below). In addition, there were some machine-related problems in entering payload ID's which could have resulted in the lower procedure scores (see comments below).

Ungrapple Tasks. Mean performance data for the Ungrapple procedural part tasks are shown in Table 4. All three subjects experienced some computer problems in entering payload ID's in the ungrapple task at some point (see comments below). One subject passed LOC 1, experienced computer problems in LOC 2 and was advanced to the Berth tasks. One subject experienced computer problems in LOC 1 and was advanced to the Berth tasks. The third subject experienced computer problems in LOC 1 but was able to complete LOC 2 and 3. Subjects were able to complete trials but unable to pass trials in which they encountered computer problems because of the penalty associated with not entering correct payload ID's. Unless otherwise noted, the performance data reported includes data from any trial a subject was able to complete regardless of computer problems.

Subjects generally found this task easy. Those subjects who did not experience computer problems in a given LOC required only two trials to successfully pass that LOC. Time required to perform the task ranged from 81 to 102 seconds. Average total scores ranged from 71% to 98%, although these scores included trials in which subjects experienced computer problems. Their best total scores were between 83% and 98%. Accuracy scores ranged from 62% to 98%, with lower scores probably due to the computer problems. Efficiency was high with scores between 89% and 100% in both the average and best trial performance data. Safety and camera scores were also high, exceeding 90%. Finally, procedure scores were low, again probably due the computer problems.

Berth Tasks. Mean performance data for the Berth procedural part tasks are shown in Table 5. Subjects found this task relatively easy, requiring only 2 trials to advance to the next LOC and failing no trials. On average, subjects required between 3 and 5 minutes to complete a trial. Their total scores exceeded 90%. Further, accuracy and efficiency scores were high, all exceeding 90%. Finally, safety, camera and procedure scores were uniformly high with scores exceeding 88% for average and best trial performance.

Unberth Tasks. Mean performance data for the Unberth procedural part tasks are shown in Table 5. Similar to the Berth tasks, subjects found these tasks easy. Subjects required only two trials to advance to the next LOC and failed no trials. Subjects required between 1.5 and 4 minutes to complete a trial for average or best trial performance. Total scores exceeded 90%. Similarly, accuracy and efficiency scores were high with scores of at least 95%. Subjects' safety and procedure scores were also high with minimum scores of 95%. Finally,

camera scores were high (between 95% and 100%) in LOC 1 and 2, although they were somewhat lower in LOC 3 (60% average; 86% best trial). This probably relates to subjects' comments regarding which camera views they prefer and whether such views are deemed acceptable by the ITS (see below).

Table 4. Mean Performance for Grapple and Ungrapple Part Tasks.

Variable	GRAP LOC 1	GRAP LOC 2	GRAP LOC 3	UNGR LOC 1	UNGR LOC 2	UNGR LOC 3
# of Trials Required to Pass	3.3	2.7	2.0	2.0^1	2.0^2	2.0^3
# of Trials Failed	0.3	0.0	0.0	0.0	0.0	0.0
Average Time per Trial (Sec.)	175.4	106.0	132.0	85.1	81.0	102.0
Best Trial Time (Sec.)	160.7	106.0	92.7	58.3	89.5	92.0
Average Total Score	86.2	90.6	85.8	71.4	81.6	98.2
Best Trial Total Score	91.3	92.6	87.7	83.4	81.6	98.3
Average Accuracy Score	88.9	91.5	93.7	62.5	97.5	87.8
Best Trial Accuracy Score	91.2	93.6	84.8	98.5	97.9	88.4
Average Efficiency Score	92.8	98.7	97.8	89.0	99.4	99.8
Best Trial Efficiency Score	94.5	98.9	99.5	99.8	99.4	100.0
Average Safety Score	92.7	100.0	100.0	95.2	100.0	100.0
Best Trial Safety Score	100.0	100.0	100.0	100.0	100.0	100.0
Average Procedure Score	70.7	78.3	63.3	43.1	50.0	100.0
Best Trial Procedure Score	80.0	86.7	66.7	53.3	50.0	100.0
Average Camera Score	93.6	84.8	91.7	94.2	90.2	100.0
Best Trial Camera Score	100.0	95.6	100.0	100.0	90.2	100.0

Note: GRAP indicates Grapple tasks. UNGR indicates Ungrapple tasks.
Note: A computer problem relating to entering data from the keyboard
prevented subjects from being able to successfully complete trials in the
Ungrapple LOC 1 and 2 tasks. The problem was resolved, enabling one subject
to complete LOC 2 and 3.

[1] Only one subject passed LOC 1. The other subjects performed 4 and 7
   trials. Their data is excluded from the # of Trials Required to
   Pass and # of Trials Failed measures.

[2] One subject passed LOC 2. One subject completed only one trial; his data
   was excluded from the # Trials to Pass and # Trials Failed measures.

[3] Only one subject completed LOC 3.

Table 5. Mean Performance for Berth and Unberth Part Tasks.

Variable	BERTH LOC 1	BERTH LOC 2	BERTH LOC 3	UNBERTH LOC 1	UNBERTH LOC 2	UNBERTH LOC 3
# of Trials Required to Pass	2.0	2.0	2.0	2.0	2.0^1	2.0^2
# of Trials Failed	0.0	0.0	0.0	0.0	0.0	0.0
Average Time per Trial (Sec.)	182.7	223.8	282.2	108.8	210.0	240.5
Best Trial Time (Sec.)	188.0	217.7	291.0	93.3	199.0	225.5
Average Total Score	93.5	97.1	97.5	98.9	99.2	94.5
Best Trial Total Score	97.1	97.6	98.7	99.6	99.5	96.7
Average Accuracy Score	92.3	95.8	96.2	98.3	98.8	98.1
Best Trial Accuracy Score	92.1	95.9	97.2	98.7	99.6	98.6
Average Efficiency Score	94.4	95.7	95.6	98.6	96.1	95.9
Best Trial Efficiency Score	94.4	95.9	95.3	99.7	96.6	95.9
Average Safety Score	91.7	100.0	95.8	100.0	100.0	97.5
Best Trial Safety Score	100.0	100.0	100.0	100.0	100.0	95.00
Average Procedure Score	93.3	100.0	100.0	100.0	100.0	100.0
Best Trial Procedure Score	100.0	100.0	100.0	100.0	100.0	100.0
Average Camera Score	100.0	88.1	99.6	95.5	99.8	60.20
Best Trial Camera Score	100.0	92.5	100.0	100.0	100.0	86.00

[1] One subject completed only one trial in LOC 2. His data was excluded from the # of Trials Required to Pass and # of Trials Failed measures.
[2] One subject did not complete LOC 3.

Informal Comments and Observations. Subjects provided a variety of informal comments and observations relating to the Grapple, Ungrapple, Berth, and Unberth procedural tasks.

For the Grapple task, all three subjects noted that the feedback said a closer view of the end effector and the grapple fixture was needed even when the view was so close that the end effector was out of the picture. Thus, subject found the feedback was sometimes confusing and thought the camera view required by the ITS was too close. One subject suggested that the ITS include tips on how close to move the end effector to the grapple fixture. Finally, one subject noted that the ITS implied there is only one right way of setting the cameras and that this was not true.

One subject also reported that the ITS needed to provide more information on where the ITS task was starting in relation to the P2T2 Generic Procedures. Further, he suggested that a lever should be placed to the right of the master alarm on the A8U panel to make the simulator more realistic.

For all three subjects, the ITS performed very slowly in the Grapple LOC 3 task. Further, there was some machine-related difficulty in setting the payload ID's in the task.

One subject thought the ITS Grapple task would be particularly useful in learning to grapple new, unique payloads, once you have mastered the actual grapple procedure.

A trainer, observing one subject's ITS session, thought the RMS should be set up so that one has to line up the RMS directly over the grapple fixture prior to beginning the grapple procedure. The trainer also thought the procedural tasks provided effective training content to the subjects. Finally, the trainer liked the realism provided by the control panel window displayed by the ITS.

Two subjects had questions regarding the difference between release and ungrapple procedures. Further, one subject noted that the release procedure checklist wrongly indicates that the RMS is moved to the target position before monitoring talkbacks. Also, one subject noted that the P2T2 Generic Procedures did not indicate that one should set the ID's to 0 after moving to the post-release position. Finally, all three subjects experienced some computer problems in entering payload ID's and were advanced to the next LOC. This occurred in LOC 1 for two subjects and in LOC 2 for the third subject.

For the Berthing task, this subject noted that on the Orbiter there is another panel that lets the user know where the trunions are in the V-guides and further, captures the payload so that you don't have to drive it all the way in. This subject also noted that the ITS does not provide depth perception information, so one must rely solely on the Y axis. He did not think this reflected RMS tasks on the Orbiter. He also felt the ITS training for this task should only supplement the regular training.

Another subject selected the cameras differently than expected by the ITS when berthing a payload in the V-guides. This subject selected side cameras so that the furthest V-guide could be seen. One could tell the depth by the

digitals, but the visuals would also be helpful. This subject preferred Camera D although Camera C was the correct choice according to the ITS. However, the subject used Camera C because the Camera D lens was too large to focus in on the V-guides. This subject also noted that one can split the screen on the Orbiter to line up two camera views. The ITS doesn't have this capability.

One subject completed an MDF class on berthing prior to working on the ITS Berthing task. The subject reported that the Berthing task seemed more straight forward due to the MDF experience. This subject felt that the MDF lessons on Berthing and Unberthing should precede the ITS lessons on these topics. The MDF provides more information on V-guides, etc. However, he felt the ITS Grapple and Ungrapple tasks could precede the MDF lessons.

For the Unberthing task, one subject did not like the God's eye view and selected an alternate camera. Also, this subject noted that it was interesting that the ITS chose cross-bay camera views. He reported that in other RMS training, the A and D or B and C cameras are used; use of cross-bay camera views of the trunions and V-guides is the wrong technique. The experimenter's informal observation was that the ITS should indicate to the subject that the camera views are adjusted for the subject in LOC 1, and further, the ITS should explain the rationale behind its camera view selections. The trainer observing this session also noted that this task was less realistic because the dynamic motion is not modeled. That is, on the Orbiter one does not have the luxury of using one hand to input THC commands and the other to adjust camera views. Rather, both hands are needed to input THC and RHC inputs due to the dynamic motion. The trainer also reported that it would be helpful to see more of the Orbiter when the payload is out of the bay. In actual RMS tasks, one should have camera views of the whole RMS. He also suggested using a variety of payloads in the LOC 1 Unberthing task.

Procedural Tasks: Recognizing and Visualizing Singularities and Reach Limits

Recognizing Singularities. Mean performance data for the Recognizing Singularities procedural part tasks are shown in Table 6. Performance of these tasks appeared to be somewhat difficult for subjects. Subjects required between 2 and 4 trials to advance to the next LOC and failed between 0 and 1 trial on average. Subjects required little time to complete a trial (between 4 and 25 seconds on average). Subjects' total scores ranged from 76% to 100% with subjects experiencing the most difficulty in LOC 1. This might be due to their confusion about whether they were seeing one view of the RMS or three views (see comments below).

Visualizing Singularities. Mean performance data for the Visualizing Singularities procedural part tasks are shown in Table 6. Performance of these tasks appeared to be slightly more difficult than the previous Recognizing tasks. Subjects required between 3 and 6 trials to advance to the next LOC and failed between .33 and 2 trials. Subjects required between 2.5 and 5.5 minutes to complete a trial. Subjects' total scores were higher in LOC 1 (92%) than in LOC 2 (86%) and LOC 3 (78.5%), indicating that subjects found the tasks increasingly difficult. Efficiency scores remained high throughout the three LOC's, ranging between 87% and 90%. Accuracy scores, though, were highest in LOC 1 (92%) and declined in LOC 2 (85%) and LOC 3 (78%).

Table 6. Mean Performance for Recognizing and Visualizing Singularities Part
Tasks.

Variable	RSING LOC 1	RSING LOC 2	RSING LOC 3	RSING LOC 4	VSING LOC 1	VSING LOC 2	VSING LOC 3
# of Trials Required to Pass	4.0	2.7	2.0	2.0	2.7	4.5[1]	6.0[1]
# of Trials Failed	1.0	0.3	0.0	0.0	0.3	1.5	2.0
Average Time per Trial (Sec.)	24.6	17.7	3.8	11.0	156.7	183.3	316.8
Best Trial Time (Sec.)	5.7	6.7	2.0	9.0	83.7	137.5	281.0
Average Total Score	75.7	88.6	100.0	98.7	91.6	85.6	78.5
Best Trial Total Score	100.0	99.2	100.0	99.4	99.8	99.8	91.8
Average Accuracy Score	83.3	91.7	100.0	100.0	92.1	84.6	87.2
Best Trial Accuracy Score	100.0	100.0	100.0	100.0	100.0	100.0	97.5
Average Efficiency Score	77.7	79.6	100.0	95.0	90.2	88.6	86.8
Best Trial Efficiency Score	100.0	96.7	100.0	97.5	99.0	99.3	75.0

Note: RSING indicates Recognizing Singularities; VSING indicates Visualizing
Singularities.
[1] One subject did not complete Visualizing Singularity LOC 2 or 3.

Recognizing Reach Limits. Mean performance data for the Recognizing Reach
Limits procedural part tasks are shown in Table 7.   Due to out-of-date
specifications and lack of a key piece of information, subjects did not perform
LOC 6 or LOC 7, involving wrist roll reach limits and all reach limits,
respectively (see comments below).   Performance of these tasks and the
Recognizing Singularities tasks was similar. Subjects required between 2 and 4
trials to advance to the next LOC and failed between 0 and 1 trial on average.
Further, they required little time to perform the task (between 14 and 31 seconds
in LOC 1 through 5). The longer time (74 seconds) shown in LOC 6 reflects the
difficulty with the wrist roll task mentioned above.

Subjects total scores generally improved from LOC 1 (73%) to LOC 5 (93%).
This was more clearly indicated by the low efficiency (56%) and accuracy (78%)
scores in LOC 1. These scores improved in later LOC's with efficiency scores
between 71% and 86% and accuracy scores between 82% and 100% in LOC 2 through 5.

Visualizing Reach Limits. Mean performance data for the Visualizing Reach Limits procedural part tasks are shown in Table 7. Subjects found this task somewhat more difficult, requiring between 4 and 7 trials to advance to the next LOC and failing between 1 and 3 trials. Further, subjects required between 100 and 165 seconds to complete a trial. Total scores were somewhat lower than observed in other tasks with scores between 76% and 81%. Efficiency scores were relatively high, exceeding 87%. Thus, the lower total scores reflected lower accuracy in performance. Accuracy scores were between 73% and 79%.

Table 7. Mean Performance for Recognizing and Visualizing Reach Limits Part Tasks.

Variable	RRL LOC 1	RRL LOC 2	RRL LOC 3	RRL LOC 4	RRL LOC 5	RRL LOC 6
# of Trials Required to Pass	3.7	4.3	2.3	2.0	2.0	1.5[1]
# of Trials Failed	1.0	1.0	0.0	0.0	0.7	1.5
Average Time per Trial (Sec.)	29.0	16.2	15.0	14.2	31.5	74.2
Best Trial Time (Sec.)	14.0	11.3	6.7	10.0	15.3	63.0
Average Total Score	72.8	81.7	95.5	96.6	92.7	3.4
Best Trial Total Score	96.9	97.1	99.4	98.5	94.8	3.4
Average Accuracy Score	78.3	82.1	100.0	100.0	100.0	0.0
Best Trial Accuracy Score	100.0	100.0	100.0	100.0	100.0	0.0
Average Efficiency Score	56.5	80.4	82.1	86.2	70.8	13.7
Best Trial Efficiency Score	87.5	88.3	97.5	94.2	79.2	13.7

Note: RRL indicates Recognizing Reach Limits.
[1] One two subjects attempted LOC 6, performing 1 or 2 trials. However, the ITS did not provided needed information on joint angles for the wrist roll reach limit. Thus, subjects were advanced past both LOC 6 and 7.

Table 7 Continued. Mean Performance for Recognizing and Visualizing Reach Limits Part Tasks.

Variable	VRL LOC 1	VRL LOC 2	VRL LOC 3
# of Trials Required to Pass	4.0	4.0	7.5
# of Trials Failed	1.3	1.3	3.0
Average Time per Trial (Sec.)	100.6	165.6	116.5
Best Trial Time (Sec.)	58.3	95.7	65.0
Average Total Score	81.2	78.1	76.3
Best Trial Total Score	98.0	98.3	99.5
Average Accuracy Score	78.7	75.3	72.9
Best Trial Accuracy Score	100.0	98.3	100.0
Average Efficiency Score	88.6	86.7	86.8
Best Trial Efficiency Score	92.0	98.1	98.0

NOTE: VRL indicates Visualizing Reach Limits.

Informal Comments and Observations. Subjects provided a variety of informal comments and observations relating to the Recognizing and Visualizing Singularities and Reach Limits procedural tasks.

For the Recognizing Singularities task, all three subjects were confused by the ITS instructions, thinking that the ITS was displaying three different RMS configurations rather than three different views of one RMS configuration. One subject also thought that the ITS highlight characteristics of an RMS in a singularity to help the user understand why the arm is in a singularity.

The trainer observing these sessions suggested there was a better way to teach individuals about singularities. He suggested that the ITS display the RMS in a singularity and demonstrate in which directions it was still able to move and in which direction it was no longer able to move. The trainer also noted that sometimes movement in more than one direction which could result in a singularity although the ITS allowed for only one correct answer. The trainer suggested that the instructions should be changed to indicate that the "correct"

answer reflected the direction which resulted in the shortest distance to the singularity. The trainer also noted one trial which exhibited an RMS configuration that had already passed through the singularity; the subject was required to move back into the singularity. He suggested that the ITS should indicate this. Further, the trainer noted that the ITS deducted 50% for moving into a software stop but failed to define a software stop or indicate how to avoid it. Finally, the trainer noted that the labeling of which THC or RHC input (e.g., +X, -X, +yaw, -pitch) would result in a singularity was confusing.

One subject had several questions regarding the characteristics (e.g., position, attitude, degrees of rotation) of different singularities and reach limits. He also did not understand the difference between singularities and reach limits and asked about the difference between reach limits, software stops, and hardware stops. The trainer observing the session demonstrated singularities and reach limits using a mechanical model of the RMS.

One subject also found it difficult to see the angles displayed by the ITS due to the quality of the graphics. This subject also reported that he would prefer to receive feedback providing an explanation rather than efficiency and accuracy scores. For example, it would be helpful if the ITS stated "the RMS is in a _____ reach limit because the angle is _____ degrees and the limits are _____ degrees and _____ degrees. He would like an explanation provided by the ITS for both correct and incorrect responses. This subject found having the trainer available to answer questions and seeing the demonstration on the mechanical model very helpful.

For the Visualizing Singularities or Reach Limits tasks, one subject commented that the ITS does not provide information on how well one drove the RMS.

For the Recognizing Reach Limits task, the instructions for the wrist roll reach limit were incorrect. The instructions referred to Spec 96; this needs to be updated to OI21. Because Spec 96 was out of date and did not provide joint angles, the ITS was advanced to the Visualization task. Thus, subjects did not complete LOC 6 (although two subjects performed 1 or 2 trials) or LOC 7.

For the Visualizing Reach Limits tasks, there was some question about whether the ITS answers were always correct. The subject noted that in one trial the ITS gave a negative limit as the correct answer when he observed a positive wrist yaw reach limit. Further, the subject noted that in some cases there are multiple right answers regarding which THC or RHC input would drive the RMS into a reach limit. The ITS, however, only allows for one correct answer. The subject also commented that an option to exit the lesson should be provided if the subject does not think he is understanding the concepts. Further, the trainer observing these sessions noted at least one case where the ITS said a positive wrist yaw was negative. There was some question regarding whether a wrist pitch trial was also labelled incorrectly by the ITS.

Survey of Content Knowledge

Two subjects answered 30 out of 33 questions correctly on the survey of content knowledge, with 1 error each in the questions relating to coordinate

systems, task procedures, and singularities. The third subject answered 24 out of 33 questions correctly. This subject made 3 errors in the questions relating to coordinate systems, 4 errors in the procedures questions, and 2 errors relating to singularities. The first two subjects completed the survey approximately 4 weeks after the final ITS lesson; the third subject completed the survey approximately 3 weeks after the final ITS lesson.

Transfer Performance Measures

Two subjects were observed on 4 of the 5 tasks: fly-to positions/attitudes, grapple, ungrapple, berth, and unberth procedures. Due to time constraints, these two subjects did not perform the grapple procedure during the SES session in which they were observed. Further, the training content of the SES session was revised for the third subject to more adequately address his training needs. Thus, data was only available for the grapple procedure for the third subject.

For the **fly-to positions/attitudes** task, four raters observed that one subject used multiaxis maneuvers sometimes or most of the time while a second subject did not use them at all. Both subjects maneuvered in vernier rate within 10 feet of structures. Both subjects hit either a reach limit or a singularity while performing the fly-to. One subject moved the RMS with 12 inches and 10 degrees of the target position and attitude by using the digitals. The other subject did not use the digitals and moved the RMS to a final position/attitude more than 12 inches and 10 degrees from the target. Both subjects required between 25 and 30 minutes to complete the task and followed either an inefficient or acceptable path rather than an efficient path.

Two raters observed one subject performing the **grapple** procedure. This subject performed the correct sequence of steps and maneuvered in vernier rate within 10 feet of structures. He hit no singularities or reach limits. The subject moved the RMS to within 12 inches and 10 degrees of the target using an inefficient path but good camera views of the payload and orbiter. He required approximately 20 minutes to perform the task.

Subjects performing the grapple, ungrapple, berth, and unberth tasks always followed the correct sequence by using the manual provided in the SES. Indeed, one purpose of the SES session was to instruct students in the appropriate use of the manual and to describe the information available in it.

For the **ungrapple** task, a release procedure was observed. Four raters observed that both subjects performed the correct sequence of steps. However, only one subject maneuvered within vernier rate within 10 feet of structures. One subject also hit both a reach limit and a singularity. By using digitals, both subjects maneuvered within 12 inches and 10 degrees of the target position/attitude. Both subjects were rated as following either an acceptable or efficient path and using good camera views. Finally, subjects required approximately 5 minutes to complete the task.

For the **berth** task, the four raters observed that both subjects performed the correct sequence of steps and moved in vernier rate within 10 feet of structures. Subjects did not fly into any reach limits or singularities. Subjects maneuvered within 12 inches and 10 degrees of the target

position/attitude, using an efficient path, and good camera views. One rater noted that one subject performed the task particularly well, scanning constantly, using multiaxis maneuvers to keep the drift small, and switching frequently from translation to rotation digitals.

For the **unberth** task, raters observed that both subjects followed the correct sequence of steps, moved in vernier rate within 10 feet of structures, and flew into no reach limits or singularities. Raters also observed that subjects maneuvered within 12 inches and 10 degrees of the target position/attitude but indicated that this was too great a tolerance for this task. Raters observed that subjects followed an efficient path and used good camera views. Subjects required between 20 and 25 minutes to complete the task.

As a final note, the trainers observing the SES sessions informally commented that they did not perceive a performance difference between subjects who had completed the ITS-modified training and other astronauts they had trained previously.

Qualitative Data

Subject Opinion Survey. The subjects generally agreed that the ITS is a useful supplement to the training provided on the higher fidelity simulators (M = 4.7). More importantly, subjects felt that an ITS (assuming adequate task instructions and accurate content) can be an effective training supplement to the higher fidelity simulators (M = 5.7). However, subjects did not agree on when in the training flow an ITS would be most effective. One subject thought an ITS would be most useful after some initial use of the high fidelity simulators. Another subject thought an ITS would be most useful as a reviewing tool following RMS 2000 level training. The third subject thought an ITS could be useful prior to beginning RMS 2000 level training, simultaneously with use of the high fidelity simulators, or as a reviewing tool following RMS 2000 level training. One subject commented that a good ITS could be built to supplement RMS training and teach basic skills. Another subject thought that the current ITS could with modest upgrading be used as a reviewing tool following RMS 2000 level training, but for initial training an ITS would need to provide much more comprehensive analysis of students' performance in comparison to the desired performance. In addition, he thought more detailed and explicit hints would be helpful.

The subjects also thought that the ITS they used was at least moderately effective in conveying training content (M = 4.3) and providing basic concepts relevant to RMS use (M = 4.0). One subject added that the ITS was better at visualizing concepts than explaining how to move the RMS in 3 dimensions. Further, subjects felt they had learned the ITS tasks trained rather well (M = 5.3). One concern was that subjects thought the task instructions relating to operating the ITS could be better (M = 3.3). Subjects reported often needing assistance from an experimenter or trainer to complete ITS tasks (M = 6.0) and often being unable to complete ITS tasks relying only on ITS task instructions, the Workbook, and the PDRS P2T2 Generic Procedures (M = 3.3). The additional information required often related to characteristics of the ITS itself.

Subjects liked working on the ITS moderately well (M = 3.7), although one subject liked working on the ITS much better (5.0) after receiving the briefing

on coordinate systems than before (3.0). Further, one subject found the ITS tasks instructive and fun in general, although he found the rotation tasks in Orbiter Unloaded particularly frustrating and this difficulty is reflected in all three subjects' data. Two subjects felt very comfortable working on the ITS in general ($\underline{M}$ = 5.5) and working on it independently for short periods of time ($\underline{M}$ = 5.0), although one subject was not comfortable (2.0). All three subjects found it convenient to use the RMS (easy to schedule, etc.) ($\underline{M}$ = 5.7). Finally, subjects reported investing much effort in trying to successfully complete ITS tasks ($\underline{M}$ = 5.7) although they also thought the ITS encouraged trying to beat the system rather than understand the concepts ($\underline{M}$ = 6.3).

Trainers' Opinions. Two trainers who possessed Space Shuttle and/or Space Station training experience provided a variety of informal comments and observations relating to the ITS.

Determining ITS Purpose and Goals. A major issue for the trainers was that prior to developing or modifying an ITS, trainers need to decide what the ITS should teach. They thought that trainers had not adequately determined the purpose of the current ITS and thus, the current ITS might have been too ambitious, perhaps teaching content that was too advanced. For future ITS development or modification, the trainers thought it was very important to know what should be taught in terms of the technical content, assumptions to be made about students (i.e., the student model), and how ITS content should be taught (i.e., the instructor model).

Cognitive versus Psychomotor Training. Moreover, the trainers thought the system should be training and assessing knowledge rather than performance (which includes skills and knowledge). They did not think the ITS should be a psychomotor trainer. Rather, the ITS should do more cognitive training, and conceptual knowledge should be evaluated.

The trainers noted that the kinematic system modelled in the current ITS restricted the ITS to low level training. The trainers thought that the ITS would need a higher level (higher fidelity) simulation in order to provide higher level training.

Level of Task Difficulty. The trainers thought that the ITS in its current form assumed students had some previous RMS experience, perhaps assuming too much knowledge on the part of the students. The current ITS was much more effective when an instructor was present to facilitate the training. Students found it difficult to learn from the ITS alone, needing more substantial instructional content than provided by the current system. The trainers suggested that if the ITS was designed to provide more advanced training content, it should offer some remedial training or more substantive help messages addressing prerequisite information and skills. They also thought that the online help messages for the ITS tasks needed to be more informative.

Similarly, the trainers thought the tasks in the ITS were at times inappropriate. For example, the ITS asked students to perform a task in a given mode whereas in reality one would use the easiest mode available for performing any given task. Also, one would use multiple modes if this made performance of the task easier. They suggested that the ITS use more plausible and simpler

tasks in both demonstrations and task practice.

Finally, trainers would like to see intelligence in the part tasks as well as in the whole tasks. Currently, the intelligent component of the ITS resides within the whole tasks. However, they felt the tutoring provided even in the whole tasks was insufficient.

Determining ITS Instructional Strategies. The trainers thought that more effort should be devoted to determining how best to teach the ITS content. The trainers thought that we needed better "education" in the ITS. The software is very sophisticated and the educational philosophy and techniques used are too simple in comparison. The trainers had several suggestions regarding instructional strategy. These suggestions were based on using multiple modes of instruction. For example, a three step approach could be used: provide substantial initial information regarding a task, provide a demonstration of the task, and then allow students an opportunity to perform the task. A more comprehensive approach might be to have the student read about the task, see it, hear/read a lecture about it, be tested on it, review it, then finally perform it. Also, in the future one could use more modelling: see it done, visualize it, then do it.

Student Modelling: Evaluation and Remediation. The trainers thought the ITS needed to more effectively evaluate and remediate students right from the start. That is, the ITS should examine what training (ITS or other) has been completed by the student, how adequately the student performs the task trained, and then predict what should be taught next on the basis of this information. Further, the system should incorporate more repetition of information that needs to be retained. In addition, the trainers recommended that the student model be individualized--it should not assume that all students are the same. The ITS should assume that students bring different skills to the task and learn in different ways.

Coaching and Feedback. A related issue was the coaching and feedback function of the ITS. That is, the trainers thought that an ITS needs a stronger coaching function in order to be a true ITS. They felt that the coaching provided (i.e., help messages, hints) was insufficient in both the part and whole tasks. They suggested that to devise a better coaching function, one could collect verbal protocols from subjects to determine the kinds of questions asked. The trainers also thought that it would be helpful in designing and/or modifying an ITS to spend more time with trainers to develop the training content and coaching information. The trainers noted that they did not have much time to give but that they needed to give more time in the future during the development or modification of an ITS to improve the coaching function.

The trainers were also concerned about the feedback provided. They thought the performance numbers were not helpful. More specifically, the system would be more effective if it provided more detailed information, especially on performance inadequacies. They suggested that the system could provide qualitative descriptions of performance, such as a "good"/"poor" evaluation followed by narrative information on what was done wrong and what to do the next time. They also suggested that a pictorial evaluation such as bar graphs would be helpful, perhaps comparing the student with other students or the best ones.

Also, the trainers thought students should receive positive feedback when they perform a task correctly to reinforce, motivate, and inform the student. However, the feedback in the current system was more negative in tone. Moreover, trainers thought the system needed to provide more specific positive and negative feedback. The trainers were also concerned that the ITS puts students into an endless loop. That is, the ITS always told students they needed more training, i.e., advanced them to the next LOC. They thought the ITS should provide clearer endings to parts of training. (This sounds like an issue relating to student motivation.) Further, the trainers thought the ITS required too much time, noting that if students passed a few trials then failed one trial, they had to begin again.

Other Issues. The trainers suggested that students needed to learn camera viewing skills earlier. For example, camera viewing skills would have facilitated subject's performance of coordinate systems tasks. A broader issue was that the ITS was able to do many things that subjects did not know about. For example, changing camera views could have facilitated coordinate system tasks, but subjects were not told they could manipulate camera views or how to use the cameras prior to or during these tasks.

The trainers also commented that the God's Eye View should be used only in demonstrations and in help messages. It should not be used in tasks performed by students. Further, trainers noted that the ITS should be able to handle multiple correct ways of performing the task. Finally, at higher levels of ITS tasks, the trainers thought the ITS should allow for more "free playing". This type of activity was only allowed in simulation mode in the current system.

Discussion and Conclusions

The results indicated that subjects were generally able to learn RMS tasks taught by the ITS. Two of the three subjects were able to correctly answer 33 out of 36 conceptual question relating to RMS use, indicating that subjects gained substantial conceptual knowledge using the ITS. Further, ITS performance data indicated that subjects successfully completed ITS lessons on coordinate systems, procedural tasks such as grapple, ungrapple, berth, and unberth, and singularities and reach limits. Similarly, transfer task performance data indicated that subjects were able to perform the 5 tasks assessed (fly-to's, grapple, ungrapple, berth, and unberth), and in addition, the trainers present during SES sessions perceived that subjects receiving ITS-modified training performed as well as other astronauts they had trained. Thus, the ITS-modified training was not perceived to be dysfunctional. Indeed, the knowledge gained using the ITS helped subjects perform tasks on the SES, providing evidence of positive transfer of training between the ITS and the SES.

Further, subjects reported that the ITS presented training content and basic RMS concepts moderately effectively. Subjects thought they had learned to perform the ITS tasks rather well although there was some concern that the ITS encouraged them to try to beat the system rather than learn the concepts. In addition, subjects viewed the current ITS as at least moderately effective in supplementing training and perceived a well-designed ITS to be a very useful and effective supplement to training on higher fidelity simulators. Finally, trainers reported that a well-designed ITS could be a very effective supplement

to training on higher fidelity simulators, although they had several suggestions for improving the current ITS.

Some caution must be used in interpreting these results in view of the small sample, i.e., two trainers and three astronauts. Specifically, it is unclear to what extent the performance data, opinions, and suggestions obtained generalize to other trainers and astronauts. For example, other trainers might not agree with all of the opinions stated. Moreover, the astronauts who participated in this project were new to the space program. Thus, more experienced astronauts might have provided different suggestions for modifying the RMS ITS.

However, the results were based on a variety of measures, including ITS task performance, SES performance, a conceptual knowledge test, and self-reports from subjects and trainers. Further, there was substantial agreement across the astronauts and trainers participating in the project in terms of performance data, opinions, and suggestions. Thus, the convergence of results provides evidence in support of the efficacy of ITS's in general, and at least moderate support for the current ITS.

The results also raise several issues. Most importantly, use of the current ITS highlighted how critical it is to involve trainers/educators in the design of ITS's. Trainers/educators are needed to determine the goals and purpose of the ITS, devise the instructional strategy, and determine effective methods to evaluate students, provide feedback, and tutor or coach students. While the software for ITS's are very sophisticated, more work is needed to ensure that the educational/instructional component is of the highest quality. That is, while the timing and placement of hints, help, task instructions, and feedback is important, one must also ensure that the content of these forms of information is accurate and of sufficient detail to most facilitate learning. A strong partnership is required between software developers and trainers or task experts to ensure that the content of ITS training matches as closely as possible the content provided by a good trainer.

Second, trainers and subjects had a variety of suggestions for improving the current ITS or developing new ITS's. A major concern related to the instructional strategy used, with suggestions to revise the ITS to incorporate a multiple mode strategy, e.g., provide substantial instructions, demonstrate, then have subjects perform the task. Trainers and subjects also suggested revisions to the feedback and coaching/tutoring provided, indicating a need for more descriptive, detailed information and less of a focus on scores. Finally, trainers recommended that ITS training should be individualized with the sequence of training determined by each individual's needs and abilities.

Third, an issue raised by the ITS-modified training related to the sensitivity of the performance measures. Subjects were required to perform at certain levels to pass a given trial, so subjects' scores were generally high. High scores imply that subjects have mastered a given task. However, subjects reported differential amounts of difficulty with various tasks and differing levels of perceived competence. This might be due to individual's perceptions of themselves. Alternately, it might reflect a lack of sensitivity in the performance measures to adequately differentiate among individuals. For example, the performance criteria could be very lenient or very stringent. Thus, whether

passing a trial indicates that one has mastered the task or demonstrated some minimum level of competence depends on the stringency of the performance criteria. The ability to adjust the performance criteria makes the system more flexible, but it might make it more difficult to determine whether one has mastered the trial or merely demonstrated minimal competency. Some additional consideration might be needed to determine what levels of performance constitute novice, competent, and expert performance. In addition, given the subjects' and trainers' comments, consideration should be given to whether other additional performance information might be helpful, such as more descriptive feedback.

In conclusion, the RMS ITS appeared to be moderately effective in conveying the content it was designed to present, and individuals were able to learn that content. Thus, evidence was provided for the efficacy of this ITS. The results also highlight two very important points. First, the use of diverse measures, such as performance data, conceptual tests, performance transfer tests, and self-reports, can provide strong evidence in evaluating training systems such as ITS's, much stronger and more fine-grained evidence than could be obtained using one or a few measures. Indeed, the convergence of results in the current study enabled stronger conclusions relating to the ITS. Second, the number and variety of suggestions for improvements to the ITS indicated in the strongest possible terms the need for involving trainers and task experts in the development of ITS's. A strong partnership is needed between software developers and trainers or educators. The development of software for ITS's is very sophisticated. However, the philosophies, methods, and techniques underlying education and training are equally sophisticated. Thus, software developers have the potential to provide more effective training tools by drawing on the expertise of trainers or educators. The costs in terms of time required to involve trainers is far overshadowed by the potential benefits.

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Author Notes

PDRS Operations Checklist

P2T2 Flight Supplement

Generic Procedures

[Note: This PDRS Operations Checklist is specifically designed for
training using the P2T2 Intelligent Trainer. However, it is
intended to be as similar as possible to actual checklists that you
will use for specific missions. Therefore, information given in
this training supplement that does not normally appear in official
operations checklists is placed in brackets.]

CONTENTS   PAGE

<u>NOMINAL RETRIEVE OPS (SPAS)</u>   <u>PAGE</u>

GENERIC GRAPPLE

1. <u>SETUP</u>

A7U   CCTV   -   Config for grapple
                      -   RMS Wrist, zoom out

SM 94 PDRS CONTROL

✓PL ID   -   ITEM 3   - 0 EXEC
    ✓INIT ID   -   ITEM 24   - 0 EXEC

2.   <u>MNVR TO PRE-GRAPPLE POSITION</u>

RATE   -   as reqd (VERN within 10 ft)
BRAKES   -   OFF (tb-OFF)
MODE   -   ORB UNL, ENTER

Mnvr to Pre-grapple position

      [Pre-grapple position is defined as having the
EE approximately 5 feet from the grapple
fixture, lined up with target. In this case,
pre-grapple has the following coordinates:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-908	13.7	-494.7	270	0	180.5	0
SY	SP	EP	WP	WY	WR	

BRAKES   -   ON (tb-ON)
MODE   -   not DIRECT
JOINT   -   CRIT TEMP

3.   GRAPPLE

A7U   ✓CCTV - Config for grapple

On MCC Go for grapple,
       DAP: VRCS or free drift
       [assume you have rec'd]

RATE   - VERN (RATE MIN tb-ON)
BRAKES - OFF (tb-OFF)
MODE   - END EFF, ENTER

Mnvr to grapple envelope

```
+-----------------------------+
|           CAUTION           |
| Monitor EE tb timing to     |
| prevent EE motor burnout    |
+-----------------------------+
```

EE MODE - AUTO

EE CAPTURE sw - depress (mom)

RIGID CLOSE CAPTURE   CRITICAL TIMES (28 sec total):
✓ [ ] [ ] [ ]   CAPTURE tb - gray, then
DERIGID OPEN EXTEND   CLOSE tb   - gray, 3 sec max,
[▨]   [▨]   [▨]   then
                           RIGID tb   - gray, 25 sec max

EE MODE - OFF
BRAKES   - ON (tb-ON)

DAP: as reqd

```
+-----------------------+
| SM 94 PDRS CONTROL    |
+-----------------------+
```

PL ID   - ITEM 3   +1 EXEC
  INIT ID - ITEM 24 +1 EXEC

Record POS/ATT and JOINT ANGLES

X	Y	Z	PITCH	YAW	ROLL	PL ID

SY	SP	EP	WP	WY	WR

[GENERIC] UNBERTH

[Note: "Low Hover" is a specific position where the payload is directly
over the V-guides and Z = -650. Therefore, this value is both generic
and payload-specific and is defined below for each payload you may have
to unberth during P2T2 training.]

      1.   SETUP

           Review LOADED (Cue Card, P2T2-LOADED/
              RELEASE)

      2.   MNVR TO LOW HOVER POSITION

A7U   CCTV - Config for Mnvr to Low Hover

          ✓RATE   - VERN (RATE MIN tb-on)
           BRAKES - OFF (tb-OFF)
           MODE   - ORB LD, ENTER

          Mnvr payload to Z = -650 (LOW HOVER)
          SPASI:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-895.0	0.0	-650.0	360.0	360.0	360.0	1

SY	SP	EP	WP	WY	WR
-42.1	83.7	-88.1	-98.9	14.3	-116.3

GRO:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-1089.5	0.6	-650.0	0.3	359.5	0.0	1

SY	SP	EP	WP	WY	WR
-18.5	74.8	-68.4	-93.0	-10.0	-51.8

HST:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-1010.4	-90.9	-650.0	360.0	359.5	0.0	1

SY	SP	EP	WP	WY	WR
-37.4	92.2	-85.2	-109.2	15.4	-121.5

LDEF:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-892.1	-14.2	-650.0	0.4	359.7	90.0	1

SY	SP	EP	WP	WY	WR	
-19.2	97.5	-93.3	-78.5	-37.8	-135.9	

SPARTANH:

X	Y	Z ·	PITCH	YAW	ROLL	PL ID
-712.1	-0.6	-550.0	359.7	359.6	360.0	1

SY	SP	EP	WP	WY	WR	
-81.3	93.0	-119.3	-112.8	6.6	193.8	

IBSS:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-890.4	-94.7	-650.0	0.0	270.0	0.0	1

SY	SP	EP	WP	WY	WR	
-21.8	86.1	-82.7	-95.0	4.2	41.3	

BRAKES - ON (tb-on)

3. MNVR TO RELEASE POSITION [SPAS]

A7U CCTV - Config for Mnvr to Rel position

DAP: free drift

RATE - as reqd (VERN within 10 ft)
BRAKES - OFF (tb-OFF)

ORB LD to Release position:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-820	0	-850	90	0	90	1

SY	SP	EP	WP	WY	WR	
-34.7	+119.4	-118.6	+5.6	-0.3	-96.9	

BRAKES - ON (tb-ON)
MODE - not DIRECT
JOINT - CRIT TEMP

SPAS RELEASE

1. **SETUP**

    Review RELEASE (Cue Card, P2T2-LOADED/ RELEASE)

    ✓POS/ATT and JOINT ANGLES [SPAS]

X	Y	Z	PITCH	YAW	ROLL	PL ID
-820	0	-850	90	0	90	1

SY	SP	EP	WP	WY	WR
-34.7	+119.4	-118.6	+5.6	-0.3	-96.9

    ✓SAFING tb   -   gray
     PARAM sel   -   JOINT ANGLE

A7U   CCTV   -   RMS Wrist, zoom out

2. **RELEASE**

    On MCC Go for Release

    ✓RATE   -   VERN (RATE MIN tb-on)
    ✓BRAKES   -   OFF (tb-OFF), unless DIRECT/BACKUP
     MODE   -   END EFF, ENTER

    DAP: free drift

    EE MODE   -   AUTO

    EE RELEASE sw   -   depress (mom)

    [When OPEN tb   -   gray:

        Mnvr arm clear of GF, payload to:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-806.1	-81.0	-862.3	268.5	270.0	89.0	

    Note: It is more important to pull *straight back* on
    the arm to about 5 ft. in relation to the GF than to
    achieve these coordinates.   ]

RIGID CLOSE CAPTURE   CRITICAL TIMES (28 sec total):

✓ ▱ ▱ ▱

DERIGID OPEN EXTEND

□ □ □

DERIGID tb – gray, 5 sec max,
                          then

OPEN tb   – gray, 3 sec max,
                          then

EXTEND tb – gray, 20 sec max

BRAKES   –   ON (tb-ON)

EE MODE –   OFF

MODE   –   not DIRECT
JOINT   –   CRIT TEMP

[3. MNVR TO PRE-CRADLE POSITION

A7U   CCTV - Config for Mnvr to Pre-Cradle

┌─────────────────────────┐
│ SM 94 PDRS CONTROL   │
└─────────────────────────┘

PL ID   - ITEM 3   +0 EXEC
  INIT ID   - ITEM 24 +0 EXEC

✓RATE   - as reqd (VERN within 10 ft)
✓BRAKES - OFF (tb-OFF)
 MODE   - ORB UNL, ENTER

SPASI:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-1261.2	-145.7	-551.4	4.7	1.7	359.9	0

SY	SP	EP	WP	WY	WR
0.0	25.0	-25.0	5.0	0.0	0.0

BRAKES - ON (tb-ON)
MODE   - not DIRECT
JOINT   - CRIT TEMP

SPAS POISE FOR CAPTURE

1.   <u>SETUP</u>

A7U   Config CCTVs as reqd

SM 94 PDRS CONTROL

✓ PL ID   - ITEM 3   +0 EXEC
✓   INIT ID   - ITEM 24 +0 EXEC

2.   <u>POISE FOR CAPTURE</u>

RATE - as reqd

ORB UNL to poise for capture (✓ ITEMs 18-25)

X	Y	Z	PITCH	YAW	ROLL	PL ID
−860.0	−35.0	−768.0	44.0	291.0	226.5	0
SY	SP	EP	WP	WY	WR	
−36.5	111.2	−102.0	−14.7	−38.3	195.4	

BRAKES -   ON (tb-ON)
✓ MODE   - not DIRECT
JOINT   -   CRIT TEMP

SPAS CAPTURE

    1.   <u>SETUP</u>

        √Target overlays attached as needed

        | SM 94 PDRS CONTROL |

        √PL ID   - ITEM 3 - 0
          √INIT ID - ITEM 24 - 0

    Review <u>RMS-CAPTURE/LOADED</u> (Cue Card)

    2.   <u>CAPTURE</u>

        <u>CAUTION</u>
        Monitor EE tb timing to
        prevent EE motor burnout

A7U   CCTV, RMS/Wrist - zoom out

        RATE   - VERN (RATE MIN tb-ON)
        BRAKES - OFF (tb-OFF)
        MODE   - END EFF, ENTER

        When grapple fixture in view and stable,
          DAP: free drift

        EE MODE - AUTO
        Mnvr to GF
        EE CAPTURE sw - depress (mom)

    RIGID CLOSE CAPTURE <u>CRITICAL TIMES (28 sec total)</u>:
    √ ☐   ☐   ☐   CAPTURE tb - gray, then
    DERIGID OPEN EXTEND   CLOSE tb - gray, 3 sec max,
                         then
                 RIGID tb - gray, 25 sec max

```
EE MODE   -  OFF
BRAKES    -  ON (tb-ON)
✓ MODE    -  not DIRECT
JOINT     -  CRIT TEMP
```

┌─────────────────────────┐
│ SM 94 PDRS CONTROL   │
└─────────────────────────┘

```
PL ID      -  ITEM 3    +1 EXEC
  INIT ID  -  ITEM 24   +1 EXEC
```

[GENERIC]' BERTH

1. SETUP

    DAP: B/AUTO/VERN

    ┌─────────────────────┐
    │ SM 94 PDRS CONTROL │
    └─────────────────────┘

    ✓ PL ID   - ITEM 3   +1
       ✓ INIT ID - ITEM 24 +1

    CCTV -   Point CCTV as reqd toward EE/GF interface
                  for view of uncmd derig/rel

2. MNVR TO LOW HOVER

    RATE - as reqd

    ORB LD to Low Hover (✓ ITEMs I8-25):
    SPASI:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-895.0	0.0	-650.0	360.0	360.0	360.0	1

SY	SP	EP	WP	WY	WR
-42.1	83.7	-88.1	-98.9	14.3	-116.3

GRO:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-1089.5	0.6	-650.0	0.3	359.5	0.0	1

SY	SP	EP	WP	WY	WR
-18.5	74.8	-68.4	-93.0	-10.0	-51.8

HST:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-1010.4	-90.9	-650.0	360.0	359.5	0.0	1

SY	SP	EP	WP	WY	WR
-37.4	92.2	-85.2	-109.2	15.4	-121.5

LDEF:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-892.1	-14.2	-650.0	0.4	359.7	90.0	1
SY	SP	EP	WP	WY	WR	
-19.2	97.5	-93.3	-78.5	-37.8	-135.9	

SPARTANH:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-712.1	-0.6	-550.0	359.7	359.6	360.0	1
SY	SP	EP	WP	WY	WR	
-81.3	93.0	-119.3	-112.8	6.6	193.8	

IBSS:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-890.4	-94.7	-650.0	0.0	270.0	0.0	1
SY	SP	EP	WP	WY	WR	
-21.8	86.1	-82.7	-95.0	4.2	41.3	

A8U   BRAKES   -   ON (tb-ON)

3.   BERTH

CCTV   -   Config for berth

RATE   -   as reqd (VERN when near structure, -10 ft; below Z = -600)

BRAKES   -   OFF (tb-OFF)
MODE   -   ORB LD, ENTER

A6U   DAP: free drift

Mnvr to berthed position:
SPASI:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-895.0	0.0	-413.7	360.0	360.0	360.0	1
SY	SP	EP	WP	WY	WR	
-29.1	69.0	-123.0	-45.8	16.9	-129.5	

GRO:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-1089.6	0.6	-414.1	0.3	359.5	0.0	1

SY	SP	EP	WP	WY	WR
-5.5	65	103.9	50.1	-10.5	-65

HST:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-1010.4	-90.9	-414.1	360.0	359.5	0.0	1

SY	SP	EP	WP	WY	WR
21.5	86.8	128.7	-55.5	18.1	137.8

IBSS:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-890.4	-94.7	-415.6	0.0	270.0	0.0	1

SY	SP	EP	WP	WY	WR
-6.8	73.8	-117.7	-46.7	4.4	26.3

LDEF:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-892.2	-14.2	-399.6	0.4	359.7	90.0	1

SY	SP	EP	WP	WY	WR
-0.1	79.2	-127.9	-41.2	-40.5	-160.4

SPARTANH:

X	Y	Z	PITCH	YAW	ROLL	PL ID
-712.1	-0.5	-423.1	359.7	359.6	360.0	1

SY	SP	EP	WP	WY	WR
-79.4	79.7	-137.8	-80.9	8.1	192.5

A8U   BRAKES - ON (tb-ON)

4. <u>PREP FOR UNGRAPPLE</u>

To relieve strain:
    DAP: VRCS or free drift

        BRAKES - OFF (tb-OFF)
        MODE   - TEST, ENTER
        Wait 5 sec, then
        BRAKES - ON (tb-ON)

5. <u>UNGRAPPLE</u>

A7U CCTV, RMS/Wrist - zoom out

CRT PL ID   - ITEM 3   +0 EXEC
          INIT ID   - ITEM 24   +0 EXEC

DAP: VRCS or free drift

A8U RATE   -   <u>VERN</u> (RATE MIN tb-ON), when within
                     10 ft of structure
        BRAKES - OFF (tb-OFF)
        MODE   - END EFF, ENTER

┌─────────────────────────┐
│   <u>CAUTION</u>   │
│ Monitor EE tb timing to │
│ prevent EE motor burnout│
└─────────────────────────┘

If single joint,
  Perform Manual EE Release

EE MODE   - AUTO
RELEASE sw - depress (mom)

When OPEN tb - gray,
  Mnvr arm clear of GF, orbiter, payload

X	Y	Z	PITCH	YAW	ROLL	PL ID
-908.2	13.7	-494.7	270.0	0.0	180.5	0

RIGID CLOSE CAPTURE   <u>CRITICAL TIMES (28 sec total)</u>:
✓ ▱   ▱   ▱   DERIGID tb - gray, 5 sec max,
DERIGID OPEN EXTEND   then
   ☐   ☐   ☐   OPEN tb   - gray, 3 sec max,
                                          then
                           EXTEND tb - gray, 20 sec max

BRAKES - ON (tb-ON)

EE MODE - OFF

✓MODE   - not DIRECT
 JOINT   - CRIT TEMP

[6. <u>MNVR TO PRE-CRADLE POSITION</u>

A7U   CCTV - Config for Mnvr to Pre-Cradle

SM 94 PDRS CONTROL

PL ID   - ITEM 3   +0 EXEC
  INIT ID - ITEM 24 +0 EXEC

✓RATE   - as reqd (VERN within 10 ft)
✓BRAKES   - OFF (tb-OFF)
 MODE   - ORB UNL, ENTER

X	Y	Z	PITCH	YAW	ROLL	PL ID
-1261.2	-145.7	-551.4	4.7	1.7	359.9	0
SY	SP	EP	WP	WY	WR	

BRAKES - ON (tb-ON)
MODE   - not DIRECT
JOINT   - CRIT TEMP

Survey of Concepts Regarding RMS Use

1.   In the Body Axis Coordinate System (BACS), if one translated the RMS in the -y direction, the RMS would move

      a.   toward the nose
      b.   starboard
      c.   down
      d.   port

2.   In the BACS, if one translated the RMS in the -x direction, the RMS would move

      a.   port
      b.   down
      c.   toward the nose
      d.   toward the tail

3.   In the Rotational Axis Coordinate System (RACS), if one rotated in the -yaw direction,

      a.   the RMS would rotate to starboard
      b.   the RMS would rotate down
      c.   the RMS would rotate to port
      d.   the RMS would rotate up

4.   In Unloaded mode, the Point of Resolution (POR) is defined to be

      a.   the nose of the orbiter
      b.   the tip of the EE
      c.   the origin of the BACS
      d.   a point in space, typically a point within a payload

5.   In EE mode, the POR is defined to be

      a.   the nose of the orbiter
      b.   the tip of the EE
      c.   the origin of the BACS
      d.   a point in space, typically a point within a payload

6.   In Loaded mode, the POR is defined to be

      a.   the nose of the orbiter
      b.   the tip of the EE
      c.   the origin of the BACS
      d.   a point in space, typically a point within a payload

7.   In Payload mode, the POR is defined to be

      a.   the nose of the orbiter
      b.   the tip of the EE
      c.   the origin of the BACS
      d.   a point in space, typically a point within a payload

For the questions # 8 through # 23, assume the RMS is centered over the payload bay.

8. In Unloaded mode, if one wanted to move the RMS toward the tail of the orbiter, one would move the Translational Hand Controller (THC)

    a. in
    b. up
    c. down
    d. out

9. In Unloaded mode, if one wanted to move the RMS in the +z direction, one would move the THC

    a. down
    b. out
    c. up
    d. in

10. In Unloaded mode, if one wanted to rotate the RMS toward the starboard wing, one would

    a. twist the Rotational Hand Controller (RHC) to the left
    b. twist the RHC to the right
    c. push the RHC forward
    d. pull the RHC back

11. In Unloaded mode, if one wanted to input a negative roll in the RMS, one would

    a. twist the RHC to the left
    b. twist the RHC to the right
    c. push the RHC to the left
    d. pull the RHC to the right

12. In Loaded mode, if one wanted to move the RMS over the starboard wing, one would move the THC

    a. in
    b. right
    c. left
    d. up

13. In Loaded mode, if one wanted to move the RMS in the +x direction, one would move the THC

    a. out
    b. left
    c. right
    d. in

14. In Loaded mode, if one wanted to rotate the RMS up, one would

    a. twist the RHC to the left
    b. twist the RHC to the right
    c. push the RHC forward
    d. pull the RHC back

15. In Loaded mode, if one wanted to input a positive yaw in the RMS, one would

    a. twist the RHC to the left
    b. twist the RHC to the right
    c. push the RHC to the left
    d. pull the RHC to the right

16. The EE is pointing to the port wing with the wrist camera facing the payload bay. In EE mode, if one wanted to move the RMS toward the tail of the orbiter, one would move the THC

    a. left
    b. in
    c. right
    d. out

17. The EE is pointing to the tail of the orbiter with the wrist camera pointing to the starboard wing. In EE mode, if one wanted to move the RMS in the +x direction, one would move the THC

    a. left
    b. in
    c. right
    d. out

18. The EE is pointing to the tail of the orbiter with the wrist camera pointing to the starboard wing. In EE mode, if one wanted to input a positive pitch in the RMS, one would

    a. twist the RHC to the left
    b. twist the RHC to the right
    c. push the RHC forward
    d. pull the RHC back

19. In payload mode, the payload axes are oriented such that +x points down, +y points to the starboard wing, and +z points to the tail of the orbiter. In relation to the payload axes, if one wanted to move the payload in the -x direction, one would move the THC

    a. down
    b. out
    c. up
    d. in

20. In payload mode, the payload axes are oriented such that +x points to the starboard wing, +y to the tail of the orbiter, and +z points down. In payload mode, if one wanted to move the payload in the +x direction, one would move the THC

    a. left
    b. in
    c. right
    d. out

21. In payload mode, the payload axes are oriented such that +x points down, +y points to the starboard wing, and +z points to the tail of the orbiter. In payload mode, if one wanted to rotate the payload to starboard, one would

    a. twist the RHC to the left
    b. twist the RHC to the right
    c. push the RHC forward
    d. pull the RHC back

22. In payload mode, the payload axes are oriented such that +x points to the starboard wing, +y to the tail of the orbiter, and +z points down. In payload mode, if one wanted to input a positive roll in the RMS, one would

    a. push the RHC to the left
    b. push the RHC to the right
    c. push the RHC forward
    d. pull the RHC back

23. Pre-grapple position is defined as having the EE about _____ from the grapple fixture and lined up with the target.

    a. 10 feet
    b. 2 feet
    c. 5 feet
    d. 120 inches

24. When maneuvering to the grapple envelope what mode is the RMS in?

    a. unloaded
    b. EE
    c. loaded
    d. payload

25. When maneuvering to low hover position during unberthing a payload, what mode is the RMS in?

    a. unloaded
    b. EE
    c. loaded
    d. payload

26. One should one switch the rate to vernier when the EE is _____ from the payload.

    a. 5 feet
    b. 6 feet
    c. 100 inches
    d. 120 inches

27. Generally speaking and depending on payload dimensions, low hover is a specific position where the payload is

    a. directly over the V-guides and z = -650
    b. directly over the V-guides and z = -500
    c. 10 feet above the V-guides and lined up with the target
    d. 5 feet above the V-guides and lined up with the target

28. When using all the cameras available to view the payload to be grappled, the cameras should

    a. view the grapple fixture using the wrist camera
    b. view the grapple fixture from the side using one camera and view the grapple fixture using the wrist camera
    c. view the grapple fixture from the side using one camera and view the entire payload in relation to the shuttle using another camera
    d. view the grapple fixture using the wrist camera and view the entire payload in relation to the shuttle using another camera

29. Which arm is in shoulder yaw singularity? (refer to figures)

    a. Arm #1
    b. Arm #2

30. Which arm is in planer pitch singularity?

    a. Arm #2
    b. Arm #3

31. Which arm is in wrist yaw singularity?

    a. Arm #1
    b. Arm #3

32. Is Arm #1 in a shoulder pitch reach limit?   Yes   No

33. Is Arm #2 in a wrist pitch reach limit?   Yes   No

Performance Information

Subject: _____   Date: _____

Task		
Fly-to positions /attitudes	Use of multiaxis maneuvers	1 Not at all 2 Sometimes 3 Most of the time or always

	Safety
	
	   Vernier w/in 10 ft
	
	   Reach limits
	
	   Singularities
		
		1 yes
		2 no
		
		_____ # flown to
		
		_____ # flown to

	Accuracy	1 within 12 inches 2 more than 12 inches 1 within 10 degrees 2 more than 10 degrees

	Efficiency
	
	   Time required
	
	   Path
		
		_____ minutes
		
		1 inefficient path
		2 acceptable path
		3 efficient path

Performance Information

Subject: _____   Date: _____

Task		
Grapple procedures	Correct sequence of steps	1 yes 2 no If no, describe out of step actions: (refer to PDRS Ops Checklist)

	Safety
	
	  Vernier w/in 10 ft
	
	  Reach limits
	
	  Singularities
		
		1 yes
		2 no
		
		_____ # flown to
		
		_____ # flown to

	Accuracy	1 within 12 inches 2 more than 12 inches 1 within 10 degrees 2 more than 10 degrees

	Efficiency
	
	  Time required
	
	  Path
		
		_____ minutes
		
		1 inefficient path
		2 acceptable path
		3 efficient path

	CCTV Use	1 poor views of payload/ orbiter 2 acceptable views 3 good views

Performance Information

Subject: _____   Date: _____

Task		
Ungrapple procedures	Correct sequence of steps	1 yes 2 no If no, describe out of step actions: (refer to PDRS Ops Checklist)
	Safety Vernier w/in 10 ft Reach limits Singularities	 1 yes 2 no _____ # flown to _____ # flown to
	Accuracy	1 within 12 inches 2 more than 12 inches 1 within 10 degrees 2 more than 10 degrees
	Efficiency Time required Path	 _____ minutes 1 inefficient path 2 acceptable path 3 efficient path
	CCTV Use	1 poor views of payload/ orbiter 2 acceptable views 3 good views

Performance Information

Subject: _____   Date: _____

Task		
Berth procedures	Correct sequence of steps	1 yes 2 no If no, describe out of step actions: (refer to PDRS Ops Checklist)
	Safety Vernier w/in 10 ft Reach limits Singularities	 1 yes 2 no _____ # flown to _____ # flown to
	Accuracy	1 within 12 inches 2 more than 12 inches 1 within 10 degrees 2 more than 10 degrees
	Efficiency Time required Path	 _____ minutes 1 inefficient path 2 acceptable path 3 efficient path
	CCTV Use	1 poor views of payload/ orbiter 2 acceptable views 3 good views

Performance Information

Subject: _____   Date: _____

Task		
Unberth procedures	Correct sequence of steps	1 yes 2 no If no, describe out of step actions: \ (refer to PDRS Ops Checklist)
	Safety Vernier w/in 10 ft Reach limits Singularities	 1 yes 2 no _____ # flown to _____ # flown to
	Accuracy	1 within 12 inches 2 more than 12 inches 1 within 10 degrees 2 more than 10 degrees
	Efficiency Time required Path	 _____ minutes 1 inefficient path 2 acceptable path 3 efficient path
	CCTV Use	1 poor views of payload/ orbiter 2 acceptable views 3 good views

Appendix D

ITS Survey

For each of the following questions, circle the number or letter
that best expresses your opinion.
═══

1. How effectively do you think the ITS conveyed the training
    content?

    1   2   3   4   5   6   7

    Not at   Very
    all

2. To what extent do you think you have learned the tasks
    trained in the ITS?

    1   2   3   4   5   6   7

    Not at   To a great
    all   extent

3. How effectively do you think the ITS conveyed basic concepts
    relating to RMS use?

    1   2   3   4   5   6   7

    Not at   Very
    all

4. In terms of using the ITS system, to what extent were the
    task instructions provided by the ITS adequate?

    1   2   3   4   5   6   7

    Not at   To a great
    all   extent

5. How often did you need additional information from other
    people (e.g., Kalen or Paul) to complete a given ITS task?

    1   2   3   4   5   6   7

    Not at   Very
    all

6. To what extent were you able to complete ITS tasks relying only on ITS task instructions, the workbook, and the PDRS checklist?

```
1       2       3       4       5       6       7
-----------------------------------------------------
Not at                                          To a great
all                                             extent
```

7. To what extent do you think the ITS is a useful supplement to training provided on the higher fidelity simulators?

```
1       2       3       4       5       6       7
-----------------------------------------------------
Not at                                          To a great
all                                             extent
```

8. To what extent do you think an ITS, in general (given adequate task instructions and accurate content), can be an effective training supplement to higher fidelity simulators?

```
1       2       3       4       5       6       7
-----------------------------------------------------
Not at                                          To a great
all                                             extent
```

9. Where in the training flow do you think an ITS (similar to the one you've been working on) would be most effective?

a) prior to beginning Level 2000 training on the high fidelity simulators

b) after initial use of the high fidelity simulators

c) simultaneously with use of the high fidelity simulators

d) after substantial use of the high fidelity simulators

e) as a reviewing tool after Level 2000 training is complete

10. To what extent did you _like_ working on the ITS?

```
1       2       3       4       5       6       7
-----------------------------------------------------
Not at                                          To a great
all                                             extent
```

11. How comfortable did you feel working on the ITS?

```
 1        2        3        4        5        6        7
--------------------------------------------------------
Not at                                              Very
all
```

12. How comfortable would you feel working independently on the
    ITS for short periods of time (i.e., without the presence of
    a trainer)?

```
 1        2        3        4        5        6        7
--------------------------------------------------------
Not at                                              Very
all
```

13. How convenient was it to work on the ITS (e.g., scheduling
    and availability of ITS)?

```
 1        2        3        4        5        6        7
--------------------------------------------------------
Not at                                              Very
all
```

14. How much effort did you invest in trying to successfully
    complete ITS tasks?

```
 1        2        3        4        5        6        7
--------------------------------------------------------
Very                                              A great
little                                            deal
```

15. To what extent does the ITS encourage you to try to beat the
    system rather than to understand the concepts?

```
 1        2        3        4        5        6        7
--------------------------------------------------------
Not at                                          To a great
all                                             extent
```

On the following page, please write any additional comments you
have on the previous questions (please include question number).
As well, please discuss any additional issues that were not
addressed in the questions above.